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ABSTRACT

Research on aptitude-instructional treatment interactions has shown that the relation of general ability to learning tends to increase as instruction places increased information processing burdens on learners and to decrease as instruction is designed to reduce the information processing demands on learners. This report summarizes a research project aimed at exploring and analyzing this result more deeply, through continued literature reviewing, experimental studies of individual differences in information processing during cognitive ability test performance, and instructional studies of ability-learning relationships. The research included eye movement measurement during cognitive performance and introspective reports of strategies following cognitive performance, in addition to conventional measures of error and latency. The principal implication of this project's exploratory work was that a cognitive process-based theory of aptitude for learning from instruction could be attainable, if continued research could clarify the role of executive assembly and control processes in aptitude and learning task performance. (Author)

APTITUDES AND INSTRUCTIONAL METHODS: RESEARCH ON INDIVIDUAL DIFFERENCES IN LEARNING-RELATED PROCESSES

RICHARD E. SNOW

FINAL REPORT 1975 - 1979
APTITUDE RESEARCH PROJECT
SCHOOL OF EDUCATION
STANFORD UNIVERSITY

Sponsored by
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Research on aptitude-instructional treatment interactions has shown that the relation of general ability to learning tends to increase as instruction places increased information processing burdens on learners and to decrease as instruction is designed to reduce the information processing demands on learners. This report summarizes a research project aimed at exploring and analyzing this result more deeply, through continued literature reviewing, experimental studies

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Introduction

Individual differences among learners constitute an important class of variables in research on instruction. Their study has been of interest, at least since Binet, because measures of these variables, often called "aptitudes", usually predict response to instruction. There is renewed interest in this fact today because aptitudes now appear often to interact with instructional conditions, i.e., to relate differently to learning outcome under different instructional treatments. These aptitude-treatment interactions (ATI) have important practical and theoretical implications.

The practical interest stems from the possibility that ATI can be used to adapt instruction to fit different learners optimally. Previous attempts at individualizing instruction have generally failed to eliminate individual differences in learning outcomes. Actually, all attempts at individualizing instruction rest explicity or implicitly on hypothesized interactions between some aptitude and treatment variables, but most work on adaptive instruction has failed to formulate such hypotheses explicitly or to study them directly. ATI can be used to assign learners to differing instructional methods or sequences, providing a kind of "macroadaptation" of instruction, as well as to guide and evaluate "microadaptive" approaches such as those used in computerized instruction.

ATI are of theoretical interest because they demonstrate construct validity for aptitude and learning measures, and suggest that common psychological processes underly both kinds of variables. It is likely that neither aptitude constructs nor learning processes can be understood fully without reference to the other.

Navy training efforts face difficult problems in assuring that all trainees reach defined levels of competence despite pronounced individual differences on entering training. Research on ATI in instructional settings is needed to devise means of reducing these problems. But more basic research on aptitude-learning relations is also needed to understand the underlying processes involved. In addition to providing guidance for instructional-level studies, basic research that analyzes aptitudes as cognitive processes in learning performance may provide suggestions useful in improving selection and performance measures, in equipment design, and in pursuing the training of aptitudes directly. Further, if important cognitive processing distinctions can be captured in new kinds of aptitude tests, such measures could provide new vehicles for commerce between laboratory-level and instructional-level research in basic and applied cognitive psychology.

This final report briefly summarizes the research findings and activities of the Aptitude Research Project, School of Education, Stanford University, during a first, three-and-a-half year phase of work on this problem, under Contract N00014-75-C-0882 with the Office of Naval Research. The present report does not attempt to reproduce or review results or data from particular studies in detail. It does provide an overview of the project and a reference to other more detailed reports and documents produced by the project during the years 1975 - 1979.

variety of ATI findings are now on hand. From their review of this research, Cronbach and Snow (1977) concluded that the existence of ATI as phenomena has been clearly established. But, while some ATI findings are plausible and some are replicable, few are well understood and none are yet applicable to instructional practice.

The volume of ATI studies can be arrayed along a continuum from laboratory experiments on individual differences in learning, through small-scale and middle-range instructional experiments, to large curriculum evaluations, naturalistic comparisons, and empirical case studies. If one constructed a frequency distribution of such studies along this continuum, it would probably appear more or less normal in form; most studies would fall in the middle range. And, the same form of distribution might be expected for instructional experiments in general, not just for ATI studies. Thus, the instructional psychology that has been popular for the last decade or two consists of short-term experiments with a few controlled instructional variables aimed at testing fairly simple propositions. Such studies seek compromise between the need for instructional relevance and the need for experimental control. But most attain neither the descriptive value of large-scale, long-term naturalistic research nor the precision and process analysis of the laboratory; inconsistencies abound in their results. Cronbach and Snow (1977) concluded that the middle-range studies were leading neither to theory nor to generalizations useful in practice. They recommended that future research pay increased attention to:

1) The examination of the most plausible ATI hypotheses in large scale, long-duration, real-school studies. This would allow a consolidation of efforts to establish a few ATI hypotheses in settings where they might actually be used. The emphasis in the design of such research would be on representativeness (Snow,1974a) and description (Cronbach,1975), rather than on laboratory-like control.

2) The development of methodology capable of handling the complexities of such research. This effort would deemphasize the familiar significance testing habits of researchers in favor of the description and analysis of complex relationships (Cronbach, 1976; Cronbach & Snow, 1977; Cronbach & Webb, 1975).

3) The development of a laboratory science for the analysis of aptitude tests and learning tasks, and the ATI constructs based on them (Snow, 1974b).

This would complement the instructional studies with process analyses to provide ideas about possible underlying mechanisms. Embodied in newly understood and/or newly designed aptitude measures, these ideas might then be conveyed to research in the real instructional settings where probable, practically useful ATI can be examined and used.

The present project defined work that would begin a long-term research program aimed at these general objectives. The Cronbach-Snow book, which provided much of the background for the project had given an extensive review of the instructional ATI literature and of improvements in the methodology of ATI research, establishing the present "state of the art" with respect to points 1) and 2) above. But it provided only a meagre introduction to the need for experimental analysis and process theories of aptitude for learning indicated in point 3) above. This project, then, aimed initially at point 3), and the coordination of research on points 1) and 3). Point 2) was not a primary objective of this work.

Brief history and starting hypothesis. The idea of a laboratory science for the analysis of aptitudes and learning tasks is not new. The topic of individual differences in learning has been of interest off and on in experimental psychology since its early days. (See the historical review by Glaser, 1967.) In one form or another it has been suggested by several contemporary writers (Gagné, 1970; Estes, 1970; Glaser, 1973, 1974). Glaser and Resnick (1972) gave examples of a variety of experiments that serve related, task analytic purposes. Some of the instructional experiments criticized by Cronbach and Snow (1977) for their inconsistencies and lack of generalizability are useful if they are reinterpreted as suggesting only possible ATI mechanisms rather than probable generalizations to instruction. They might be combined with laboratory studies, arising from the experimental psychologists' renewed interest in cognitive processes related to intellectual differences (e.g., Hunt, Frost, & Lunneborg, 1973; Underwood, 1975). These form a loose but growing collection of provocative suggestions. Some use experimental manipulations to examine the construct validity of an aptitude. Some use aptitudes to examine the construct validity of learning processes. And some might generate new conceptions of aptitude and learning as a result. But there had been no systematic compilation of this literature or development of a theoretical framework with which to organize further efforts. The last time an experimental psychology textbook had paid any extensive attention to individual differences research on individual differences. In 1957 Cronbach issued his famous call for unification of correlational and experimental psychology. This was the impetus for the growth of ATI research on instruction through the 1960's. But except for the milestone symposium edited by Gagné (1967), laboratory experimental research on individual differences in ability and learning lagged until the middle 1970's. No substantive connections between this work and ATI research on instruction had been constructed.

Yet, there were important reasons for believing that the construction and analysis of such connections would be fruitful. A variety of evidence from instructional ATI research implied that general ability differences among learners interact with instruction varying in degree of structure and control exercised over information processing (Cronbach & Snow, 1977). The general ATI hypothesis seems to be that instruction is better for high ability learners as it allows them to do more of the processing work themselves, and better for low ability learners as it provides more of the processing work for them, or otherwise simplifies and controls their cognitive activities. The evidence had both an ability and a preference or "style" aspect, since high ability learners often do poorly if structure is imposed on their work; i.e., the relation of ability to learning is sometimes negative in such conditions, suggesting some kind of stylistic or strategic interference, or motivational turnoff.

The instructional findings bearing on this hypothesis, however, were complex, unclear, and occasionally inconsistent. General ability measures are often varying mixtures of fluid-analytic reasoning and crystallized-verbal comprehension. There are subsidiary skills suspected to operate in some of these measures, reflecting speed of perceptual processing, spatial ability, and several types of memory function. The instructional treatment variables that might provide such interaction also vary in character from study to study and remain poorly defined. Structure is sometimes represented in conventional verbal instructional procedures, sometimes in televised or simulated demonstrations, sometimes in CAI. Findings cannot easily be collated across studies where treatments are identified by such global labels. Detailed task analysis of both aptitude measures and instructional treatments was clearly needed, to identify the cognitive information processing links that might provide an explanation for the ATI effects.

Military ATI studies. Though most of the instructional ATI studies supporting this general hypothesis had been conducted in public schools or colleges, several such findings had come from research on military training. These were of particular interest in the present research. Several of these studies are briefly reviewed below, to give a flavor for the kinds of ATI findings possible in military training.

Taylor and Fox (1967) reported two studies, using army enlisted men. In one, complex plotting of military data was taught, either by television with pictorial examples and a small-step programmed-instruction sequence, or by conventional lecture and practice. The TV method, which structured and simplified the learner's task, was superior -- strikingly so for men with low scores on the Armed Forces Qualification Test (AFQT). Though ATI was ordinal, implying that TV was best for all men, the high ability men did reasonably well with conventional methods, and TV is costly. Thus, training might be differentiated with benefit, using the expensive method only for trainees in the lower-aptitude range. The second study taught military map symbols, either by allowing men to use a card deck in their own idiosyncratic ways or by a controlled sequence of presentation, response, and feedback. Free pacing was best for all men but was particularly superior for high-ability trainees. The controlled or structured method showed a relatively shallow aptitude-achievement regression slope; this implies that the structured treatment might be improved specifically to benefit lower-ability men.

DePauli and Parker (1969) compared a class of Navy sonar technicians given a special training device with two other classes given instruction with conventional equipment. There was substantial ATI, using a combination of the General Classification Test and Arithmetic Test as aptitude and two measures of learning outcome. To understand the interaction, however, Cronbach and Snow (1977) revised the reported analysis to examine regression slopes (instead of correlations) and mean differences simultaneously. The training device gave much better results for men below a score of 124 on aptitude. Among men above 130, the convential course gave better results. The Navy had been excluding from electronics training men scoring below 110, but it appeared that the trainer would allow men at this level to succeed. The trainer was a simplified set of circuits simulating the main features of sonar sensors allowing a more direct and clearer match

between theory and practice, and reducing reliance on verbal instruction. Presumably, lower ability men had difficulty with the more abstract-complex conventional instruction, where they could not extract the basic relations for themselves. Since the trainer is much less expensive than the operational sonar equipment used in the conventional course, the question remains open whether the latter has advantages over the trainer for men of high aptitude when cost is considered.

Edgerton (1958, 1956) reported two notable studies. In one, aviation mechanics were taught either by rote or by emphasizing explanations and questions. From the reported correlations, Cronbach and Snow (1977) computed rescaled regression slopes to show that verbal, reasoning, and fluency abilities were more highly related to performance in the rote condition. Explanations apparently helped lower aptitude men, while higher-aptitude men did not need them or could provide them for themselves. Reexamination of the reported multiple regression data suggested that the ATI probably arose from the action of general verbal ability. Distinctions between abilities seemed difficult to justify. But another study did show the function of special abilities. The study compared performance of weather observers taught theory first then technique, with men taught in the opposite sequence. Spatial, reasoning, and fluency abilities related more strongly to performance in the theory-first condition, while verbal, number, and memory abilities gave stronger relation in the technique-first condition. By subdividing criterion items into homogeneous categories, more detailed ATI results were obtained. These implied that the learning of weather theory requires reasoning ability if theory is taught first; teaching technique first helps men low in reasoning ability to comprehend later theoretical content. However, learning the techniques of weather observation requires numerical ability if techniques are taught first; teaching theory first helps men low in numerical ability to comprehend later content on techniques. Memory ability also correlated with performance on some items, principally in the technique-first condition. Thus, if this finding were to be substantiated it would mean that men low in reasoning and high in numerical facility should be taught techniques first; technical structure aids later theoretical learning. Men high in reasoning and low in numerical facility should be taught theory first; theoretical structure aids later technical learning. Multivariate methods had not been fully used by Edgerton in exploring this hypothesis, so it is unclear what sequence might be prescribed for men high or low in both abilities.

Other military studies relating less directly to the above general hypothesis should be noted in passing also, for they served to provide clues concerning related issues for the present research. Berliner and Melanson (1971), for example, had compared CAI and conventional classroom instruction in Morse code for army enlistees. Of eleven scores obtained from the Army Classification Battery, ten were negatively related to performance in conventional instruction and nine were positively related to performance in CAI. All the correlations were weak, so further work would be required to sharpen ATI. But negative aptitude-outcome slopes again suggest interference or motivational problems for high ability learners, while positive aptitude-outcome slopes may suggest the same for low ability learners. It was noted also in this study that CAI seemed to accentuate individual differences in outcome, contrary to the usual premise about individualized instruction.

A range of studies suggests that ATI findings cannot be understood or capitalized upon without more detailed analysis of aptitude and learning tasks. Sticht (1971) compared several versions of audio-taped instruction varying on speech rate and amount of additional information included. Men with low scores on the AFQT benefitted somewhat from the tapes with added information, but differences were small. Nagel (1968) compared formal-impersonal and informal-personal versions of programmed instruction on celestial navigation. Navy reservists without prior experience with programmed instruction, or with the subject-matter, learned more from the impersonal style. The methods were about equal for other men. Federico (1971) taught medical fundamentals to military trainees using programmed instruction, comparing audiovisual vs. printed versions and pretest vs. no pretest. With AFQT as aptitude, there appeared to be disordinal ATI; the printed version was better for low ability men, while the audiovisual version was best for high ability men. Gibson (1947) compared Air Force gunners who performed well or poorly after one of three treatments. Low men in filmed instruction had done considerably better than low men in treatments relying on manuals and lectures. This implies that film was best for men of low aptitude. Research by Tallmadge and Shearer (1969, 1971) examined performance in Navy training courses on celestial navigation, aircraft recognition, and linear programming, using a variety of ability and personality measures. No important ATI were found. Wallis and Wicks (1964) compared live teaching with two forms of programmed instruction on trigonometry, using British Navy enlistees. A pretest on mathematics correlated strongly with performance under programmed conditions and not at all under live teaching conditions, suggesting a strong disordinal ATI.

Objectives and Research Approach

Given this background, the project had three main objectives.

1) Carry on the literature review, begun above, to reach a specification of the major kinds of individual differences in aptitude presumed to be influencing learning processes and hypotheses about their relation to one another and to manipulable characteristics of instructional learning tasks. The review was to concentrate, particularly, on the general ability-information processing burden hypothesis outlined above, using both laboratory research to suggest possible mechanisms that might underly instructional ATI phenomena and other ATI findings derived from instructional studies to organize these suggestions. It ignored research on individual differences that could in no reasonable way be construed as relevant, ultimately, to instructional learning.

2) Conduct a series of experiments designed as task analyses of individual differences in aptitude for learning, with the aim of constructing an information processing model of general ability and its major constituents. Such experiments would manipulate stimulus conditions expected to control either information processing activities in aptitude test performance, or the relation of aptitude tests to some stage of processing in a learning or performance task, or the relation between aptitude tests purporting to measure distinct but similar constructs. They would be designed also to explore the value of collecting eye movement tracks during performance and introspective accounts by subjects, as well as error and latency measures, as data for the purpose of aptitude process analysis.

3) Conduct real instructional experiments designed to replicate and/or elaborate ATI hypotheses suggested by the literature as identifying processes underlying particular ATI phenomena.

The expectation was that exploratory analysis of both aptitude measures and instructional learning tasks would allow the identification of common processing links to account for the molar aptitude-learning relationships. It was also expected that results would suggest how aptitude tests and learning tasks might be redesigned to sharpen the measurement of process variables involved in such relationships.

Results and Discussion

This section is organized under three headings, corresponding to the three main objectives of the project. A summary and conclusions section then completes the overview.

Review and reanalysis of literature and methodology. Technical Report No. 1, (see Snow, 1976a) attempted to bring the literature review of instructional ATI studies, begun originally by Cronbach and Snow (1977), up to date with respect to two hypotheses. One of these was the general ability - information processing burden hypothesis that provided the main focus of the present project. This was termed the $G_cG_fG_v$ complex, to signify that the general ability construct is typically thought to contain fluid, crystallized, and visualization ability constituents. The other hypothesis concerned evidence that anxiety, achievement via independence and achievement via conformity were motivational aptitudes often interacting with instructional treatment contrasts characterized as structured vs. participative, or conforming vs. independent, or teacher-centered vs. student-centered. This was termed the $A_iA_cA_x$ complex. While personality and motivational aptitude constructs and associated ATI hypotheses were not to be a focus of this first project, it was recognized that ultimately their involvement in the cognitive aptitude-learning network would need to be recognized and investigated. Another review chapter (Snow, 1978a) added isolated other studies to the summary of evidence bearing on both these aptitude complexes.

Technical Report No. 1 also reviewed two methodological developments pertaining to instructional ATI research. These concerned the need to separate between-class and within-class regression components in studies involving multiple classrooms, and the problems posed for these and other regression analysis of ATI by the existence of outliers. Provisional approaches to both problems were demonstrated.

Finally, Technical Report No. 1 reviewed research bearing on a laboratory science of aptitude processes, under the headings of "initial stimulus processing", "short term memory", mediation and transformation", "reasoning and problem-solving", "strategies and structure", and "response integration and retention". This was admittedly a first cut, but it formed a basis for the project's continuing review in this domain.

Technical Report No. 2 (Snow, 1976b) continued the review of laboratory research, concentrating on theoretical and methodological issues. It examined various starting assumptions for basic research on aptitude processes and derived hypotheses and some further methodological principles from a review and comparison of factor analytic, associationistic, information processing, and psychometric models of aptitude.

Technical Report No. 2 also proposed a research strategy for programs of work in this area. It suggested that future research be sensitive to a distinction between four types or levels of individual differences in cognitive processes underlying aptitude and learning performance. Provisionally, these were identified as: p-variables reflecting individual differences in the efficiency or capacity of particular processing steps or components; q-variables representing individual differences in how a sequence of processing steps is organized; r-variables identifying individual differences in the inclusion of different components or processing routes; and s-variables including individual differences in the overall summation or strategic assembly and adaptation of processing across parts of particular tasks. The suggested methodology followed a general multivariate S-R-R paradigm. Guidelines were offered regarding the selection of aptitude constructs for analysis, the use of reference aptitude factors and exploratory correlation analysis, the conduct of task and componential analysis, the inclusion of learning sample tests, aptitude test revision, and, ultimately, demonstration of new conceptions of aptitude in instructional ATI studies.

Finally, Technical Report No. 2 included a review and critique of studies of short-term visual memory, to demonstrate how various theoretical and methodological principles previously discussed might be applied concretely. Some process hypotheses and possible instructional applications were discussed.

Some later technical reports from the project took up particular substantive or methodological points for more detailed consideration. In Technical Report No. 6 (see Lohman, 1977a), correlational research on the relation of ability and personality variables was discussed, focussing particularly on reported relations between speed-of-closure abilities and hypnotizability. Problems of nonproportional sampling in inflating such correlations, and methods of correcting for such biases, were explored.

Technical Report No. 8 (see Lohman, 1979a) provided a detailed review and reanalysis of the correlational literature on spatial ability. It had been recognized that the traditional hierarchial model of cognitive ability factors was particularly vague in the domain of spatial and visualization abilities. Thus, this work sought to clarify the major dimensions in this domain and to derive hypotheses about processes underlying these dimensions. It was concluded that three factors could be distinguished: spatial relations, involving speed of performance on simple mental rotation tasks, with or without the actual use of mental image rotation processes; spatial orientation, involving imagined reorientations of self-object relations in space to produce different perspectives; and visualization, involving relatively unspeeded performance on complex mental transformation, construction, and matching tasks, with or without the actual use of mental image transformation, construction, or matching processes. It was emphasized that tasks designed to measure spatial abilities, especially complex and relatively unspeeded tasks, are open to the use of alternate solution strategies some of which are based on logical analytic or verbal rather than purely spatial processes.

The report concentrated also on the distinction between speed and level (or power) measurements and the nature of ability constructs based on them. It was shown that speed and level factors do not connect well with one another or with other constructs in a hierarchical model of ability organization. Speed and level abilities appear to be relatively independent, and process models of such abilities are qualitatively distinct.

Other exploratory correlational work was begun using a supplement to this project received late in the contract period. It sought to examine further the organizational structure of visual memory and reasoning abilities. It also reanalyzed previous correlational data on ability-learning relationships. Since this work was completed largely within a subsequent contract and second phase of the Aptitude Research Project, it wll not be reviewed here.

Finally, in this category, Technical Report No. 4 (Snow, 1977a) provided a general discussion of individual differences in aptitude, the implications of an individual difference view for the construction of instructional theory, and the use of information on aptitudes in instructional design.

Experimental analysis of fluid, crystallized and visualization abilities. Several different kinds of experiments were conducted to explore the kinds of measures and research designs that might be useful in process analyses of aptitude. Most sought to produce process hypotheses about one or more of the major constituents of general ability -- namely fluid-analytic, verbal-crystallized and spatial visualization abilities -- or to distinguish among them in process terms.

Technical Report No. 3 (Snow, Marshalek, & Lohman, 1976) summarized a first attempt to investigate the relationships between ability constructs and information processing parameters. Chiang and Atkinson (1976) had administered visual search, memory search, and digit span tasks to 33 Stanford students. A total of 25 of these students were administered a battery of traditional ability tests and several film tests developed by Seibert and Snow (1965). One of these film tests was designed to produce a backward masking effect in short term visual memory. Ability tests and derived factor scores were then correlated with the intercept, slope, and digit span parameters from the Chiang and Atkinson (1976) study. In general, correlations between ability tests (even the short term visual memory film tests) and information processing parameters were low. The interpretation of these low correlations laid the foundation for most of the other studies conducted during the first phase of the project. In particular, the results of this exploration suggested that a) future investigations would have to look beyond simple information processing tasks to develop an adequate explanation of general abilities; b) faceted tasks were needed to increase complexity in a systematic manner, and c) a major source of individual differences in general abilities might be found in executive assembly and control processes, and strategic adaptations.

Since the first exploratory study of individual differences in information processes (above) suggested that the method of correlating information processing parameter with ability constructs was not likely to yield much insight into general ability constructs, the second experiment focused directly on ability test performance. Aptitude information provided by the project's aptitude reference battery (Snow, et al 1977; see also Snow, 1977b; Marshalek 1977) was used both to select subjects and tasks for this experiment. Further, the potential of eye fixation tracks and retrospective subject reports for research on aptitude process was explored. The first phase of the study involved interviewing 123 Stanford students on the strategies they employed when solving items on a selected set of tests administered as part of the reference battery. These reports were used to construct checklists of strategies for each of eight tests that spanned the ability space from G_v through G_f to G_c. Six items from each of these tests were then administered to 48 students from the high school reference population of 241 Palo Alto high school students. Eye fixation tracks, errors, and latencies, were obtained for each item, along with retrospective subject reports of solution strategies on a subset of the items.

The analyses of eye fixations centered on the two experimental tasks that had highest correlations with corresponding reference tests: Paper folding and Vocabulary. Lohman (1977b) presented a preliminary report of the analyses of the eye fixations. Additional analyses were reported by Snow (1978b, 1980). For the Paper Folding test, major findings were: a) patterns of eye fixations varied markedly across items, especially as item difficulty increased; b) high ability students generally spent more time studying the stimulus figures before looking at the response alternatives, and c) the two general strategies that were used by most subjects were constructive matching (working forwards) and response elimination (working backwards). As expected, patterns of eye fixations on the vocabulary items shared less systematic variations in solution strategy since individual differences in vocabulary are largely memory based, and not obtainable from item inspection. Nonetheless, some strategic differences were noticed even on the verbal task. Overall, it was concluded that the analysis of eye fixations could significantly contribute to an understanding of problem solving processes of relatively short duration.

The analysis of the retrospective reports gathered after the experiment was reported by Yalow & Webb (1977). They computed 13 specific responses on the strategy check lists for four tests: Paper Folding, Form Board, Vocabulary, and Verbal Analogies. They found that high ability students reported often knowing the answer before examining the alternatives, while low ability students reported spending more time evaluating and eliminating alternatives. Further, low ability students reported more internal verbalization, had less confidence in their answers, and, consequently, guessed more frequently. Students of intermediate ability reported using specific spatial strategies more frequently than either high or low ability students. Correlations between the 13 strategy indices suggested three major dimensions: a) the tendency to construct a response from careful analysis of the stimuli before looking at the alternatives, i.e., the constructive matching strategy, b) the tendency to analyze the response alternatives, i.e., the response elimination strategy, and c) the tendency to solve problems by intuitive or impressionistic rather than analytic methods.

Technical Report No. 9 (Lohman, 1979b) pursued the results of the literature reviews summarized in Technical Report No. 8 (Lohman, 1979a) with an experimental investigation of the relationship between speed and level in a faceted spatial task. The study demonstrated that individual differences in speed were largely independent of level scores. Further, mental construction was experimentally and correlationally distinguished from mental rotation, and various combinations of these spatial skills were related to factors such as closure speed, perceptual speed, spatial relations, and visualization. The study also found that individual differences in task latency were generally related to individual differences in verbal ability even though correctness on the task and its facets was consistently related to spatial reference tests. These and other results strongly suggested that many subjects were able to solve this spatial task using at least partially nonspatial strategies.

This finding was pursued in the final months of the project through an experiment that attempted to manipulate solution strategy directly using another, previously studied spatial test: Paper Folding. As in previous studies, a faceted paper folding task was constructed to manipulate item complexity systematically. The experiment also contained two experimental manipulations designed to influence solution strategy. First, the stimulus parts of some items were presented one at a time while on other items the entire item was visible simultaneously. Further, on some items multiple choice response alternatives were presented while on other items the subjects were required to construct their answers. It was expected that the successively presented items and those requiring a constructed response would be less susceptible to nonspatial strategies than would simultaneously presented items or those with multiple choice alternatives.

In addition to these within-subject manipulations, subjects were assigned to one of three strategy training treatments. Some subjects viewed a film that visually demonstrated the process of mentally folding, punching, and unfolding a piece of paper. The second group was taught a strategy for coding and remembering the sequence of folds, while the third group received practice in solving items with immediate feedback. The expectation was that these strategy treatments would be differentially effective for different subjects, depending on their tested spatial and verbal abilities, and for different items, depending on their difficulty, mode of presentation, and mode of response. This study was initiated under a supplement to the present contract, and is being completed under the new contract, in the second phase of the project.

Another experiment was designed under the first contract for conduct under the second contract. The study continues the investigation of general ability as displayed on tests of analogical reasoning. It combines the type of facet analyses employed on previous experimental tasks with the methods of componential analysis developed by Sternberg (1977). In addition, eye fixation tracks are recorded while subjects solve a sampling of the items. Thus, this study represents a convergence of experimental methods developed during previous studies with those advocated by Sternberg (1977) and applied to the type of geometric analogy problems studied by Sternberg (1977) and Pellegrino and Glaser (1980). It is expected that analysis of patterns of eye fixations will permit clearer discrimination between the major competing information processing models of analogical reasoning. Further, the faceted item construction approach used in the present project should remove some ambiguities from the componential analyses of Sternberg's (1977) previous study, since predictors for the various models will be objectively determined and more nearly orthogonal. Finally, the study includes a wide range of item difficulties as well as both two and four alternative items. This should make performance on the experimental task more closely resemble performance on standard psychometric tests of analogical reasoning.

Instructional studies. Three instructional studies were conducted within the project. Each was designed to explore one or more aspects of aptitude processes in learning from instruction to characterize the kinds of complexities theory construction would have to face. They were designed to replicate or elaborate ATI hypotheses, not to test hypotheses derived from laboratory analyses of aptitude processes; their aim was to connect with and to help direct those analyses.

Technical Report No. 7 (Webb, 1977) involved a comparison of individual learning conditions and small group learning conditions in instruction on

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mathematical problem solving. Within the small group conditions, uniform ability groups and mixed ability groups were compared, by assigning membership from three general ability strata. Prior evidence on these contrasts is meagre. Yet individual vs. group learning and the optimal mix of ability levels within a group, appear to be baseline questions for instructional psychology and for ATI research. Results showed that for low-ability students, mixed-ability grouping was best, individual learning was next best, while uniform-ability grouping was worst. For medium-ability students, the order from best to worst conditions was: uniform-ability grouping, individual learning, and mixed-ability grouping. High-ability students performed equally well after learning individually or in mixed-ability groups, and less well in uniform-ability groups. More importantly, group process observations showed that in mixed-ability groups, high-ability students explained to less-able members; they did not do so when grouped with other highs. High-ability students who took the role of explainer showed excellent delayed performance, while low-ability students who received such explanations did better than those who did not. Medium-ability students tended to participate most actively in uniform ability groups and did their best when in those conditions. Thus, the effect of the instructional setting depended on the ability of the student, the ability of the student relative to teammates, and the role the student adopted in group interaction.

Technical Report No. 10 (Snow, Wescourt, & Collins, 1980) sought to construct a correlational ability-learning network to include measures of aptitude before instruction, learning activities during instruction, overall learning curve characteristics, and learning outcome. Interactive computerized instruction in computer programming language served as the learning vehicle. It was found that individual differences in learning increased substantially over 15 hours of instruction, and that these differences were significantly predictable from aptitude information available one-and-a-half years before entering the course of instruction. It appeared that performance in the course was highly related to fluid-analytic ability, and to a personality variable called "independence-flexibility", but was not related to verbal-crystallized ability. Learning activity indices, quantified from the protocols maintained for each student by the computer, showed relations to aptitudes, learning curve characteristics, and learning outcome. The patterns of relationships in the network suggested that the learning activity protocol approach could be used to define learning style differences among computer programming students that offered a more detailed account of aptitude-learning relationships.

Technical Report No. 12 (Yalow, 1980) tested the general ATI hypothesis, and a differential ATI hypothesis that contrasted fluid-analytic and verbal-crystallized ability, with a two-week instructional program in economics. Three alternative instructional treatments were contrasted. A minimum treatment provided only bare-bones exposition of supply-demand and related principles and thus demanded substantial elaborative information processing on the learner's part. Two elaborated treatments provided either verbal explanation and exercises or figural-graphic exposition and manipulation. Both immediate learning and retention measures were faceted tests, to allow distinction between verbal and figural performance and between concept learning and problem solving.

The general ATI hypothesis was replicated on the immediate posttest. Apparently, the instructional treatments that compensated for inaptitude by giving less able learners the elaborated structure and directions they needed, also obstructed to some extent the progress of more able students. ATI results were similar for both direct learning and problem-solving. The differential ability effect was slight and nonsignificant. Its trend suggested that verbal elaboration was somewhat better for students with G_c ability greater than G_{fv} ability, while figural elaboration was a bit better for students with G_{fv} ability greater than C_c ability. Were it sharper this result would favor a capitalization or preferential hypothesis (see Cronbach & Snow, 1977): one does best with instruction that fits one's strengths. Verbal elaboration particularly helped verbal posttest performance while figural elaboration particularly helped figural posttest performance.

On the delayed test, the ATI effects diminished or disappeared. More importantly, the minimum treatment produced by far the best retention, especially for students high on G_c ability. Figural elaboration was particularly bad for the retention of figural posttest performance. On this part of the test, the verbal elaboration treatment almost matched the positive effects of the minimum treatment, for almost all students. To a lesser extent, verbal elaboration was relatively bad for the retention of verbal posttest performance. The problem subtest, however, still showed the same though nonsignificant ATI pattern on the delayed test that it had shown on the immediate test.

The implications deserve more detailed analysis. If only immediate achievement is considered, and aptitude is ignored, then elaborated instruction appears beneficial. If general ability is added to test ATI, then elaboration appears to help less able learners but is not optimal for more able learners. If one must further choose a particular form of elaboration to give to less able learners, it appears best to match the form to the learner's relative strengths. However, when retention is considered, all this changes. Unelaborated instruction is best for almost all learners, but particularly for students high in crystallized verbal ability. And, here, if one must choose a form of elaboration, it appears best to mismatch the form with a student's differential ability profile. Apparently, retention requires a degree of cognitive organization that is best promoted, for a given individual, by instruction that is incomplete for that particular individual. Thus, if instruction does too much for students, the resulting achievement may be too weakly or narrowly organized.

Summary, Conclusions, and Implications

The starting hypothesis for this project was that instruction appears better for high ability learners as it allows them to do more of the information processing work involved in learning for themselves; and better for low ability learners as it provides more of the processing work for them by simplifying and controlling their cognitive activities. It seemed clear that individual differences come into play upon situational demand. ATI research has continued to suggest that the relation of such general aptitudes as verbal-crystallized intelligence and fluid-analytic intelligence to learning outcome increases with the information processing demands of the instructional task. It also seemed clear that instructional task demands should be understandable in the same terms as the demands involved in performance on general aptitude tests.

The project aimed to open up this hypothesis to analysis, by examining further the past instructional ATI research and conducting selected new instructional studies, combined with a series of experiments that would pursue process analyses of the phenomena thought to underly ability-learning relationships involved in ATI. A central concern of these process-analytic experiments was to examine the distinction between fluid-analytic, verbal-crystallized, and visualization abilities as constituents of general intelligence.

The initial hypothesis continues to be sustained by the results conducted within this exploratory project. The results also make clear that the psychological phenomena involved are too complicated to yield to simple generalizations applicable in instructional practice tomorrow, but that fact was already known. What has been determined by the project can be summarized as follows:

1. Factor analytic and multidimensional scaling analyses of old and new ability correlation matrices continue to show the characteristic Guttman Radex form. Constellations of mental tests corresponding to traditional ability factors can be identified, but the smooth transition from peripheral to central abilities suggests that the traditional factor model will not fit current theoretical needs. The distinction between tests requiring sequential digital symbolic processing and those involving more holistic analogical iconic processing does seem to be borne out, however. The tendency for tests of increasing complexity to correlate increasingly with a general factor can be reinterpreted to posit the involvement in more complex tests of "executive assembly, and control" processes.

2. Evidence from several studies suggests that it may not be possible to justify in process terms the factor analytic distinctions between fluid-analytic ability (G_f) and complex visualization ability (G_v); the distinction between these and complex verbal-crystallized ability (G_c) is somewhat clearer, but not certain. Factor distinctions may have heuristic value in thinking about instruction, but are not consistently distinguishable, either in correlational studies or in laboratory experiments. It appears that, as complex tests allow alternative processing strategies, their score variance reflects a mixture of individual differences in these strategies and in shifts among them. Traditional ability factor distinctions cannot capture or partition this complex..

3. The problem is even more difficult because speed and level of performance appear psychologically distinct. G_v measures divide into those that emphasize complex power performance and those involving simple speed performance. These have quite different correlates in the ability domain: level or power scores on complex spatial tests correlate with one another and with G_f tests, declines in level scores over different kinds of item difficulty correlate with different kinds of spatial tests, while some speed scores correlate with verbal ability measures.

4. Exploratory studies of eyemovement differences and introspective reports during ability test performance suggest that one important strategy difference involves a "constructive matching" approach as opposed to a "response elimination"

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approach to complex test items in both verbal and spatial tests. An index of degree of constructive matching based on introspection reports correlated significantly with 20 of 35 ability tests, and principally the more complex tests. Quantifications of eye movement track and introspective report differences showed potential usefulness in research on individual differences in information processing.

5. Instructional studies persist in showing the strong relation of general abilities to individual differences in learning. One study replicated the general ATI hypothesis, that elaborated instructional treatments help low ability learners, not high ability learners. It also suggested, however, that the kind of cognitive organization needed for retention might not be benefited by elaborated treatments. Another study, of a computerized interactive 15-hour course on computer programming, showed that a combination of G_f aptitude and a personality variable called "independence-flexibility" predicted individual differences in learning, while G_c aptitude did not. It also demonstrated that learning activity variables could be developed to index individual differences in learning that in turn related both to prior aptitude and subsequent achievement. The aptitude-learning correlational networks thus produced may provide an important guide to task analytic experiments searching for common process links. Finally, a third instructional experiment suggested that the use of aptitude information in instructional research and development must take the learner's initial ability, the mix of ability in that person's group, and the role the person takes in group interaction, into account. There is, in short, a social psychology of aptitude to be reckoned with whenever training or instruction is applied to teams or groups.

This was an exploratory project. The overarching implication of the literature reviews, the instructional studies, and the laboratory experimental work is that a process-based theory of aptitude for learning from instruction can be reached by further research. Such research must, however, demonstrate and analyze the role of executive assembly and control processes, as well as that of "elementary" process parameters in order to connect aptitude differences with learning differences under instruction. Work under the present contract produced suggestive evidence about the nature of this aptitude-process-achievement link. A second phase of the Aptitude Research Project will need to pin down this hypothesis in terms common to aptitude test performance and instructional task performance.

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